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The Waters of the Western and Northern Coasts of Norway in July–August 1957

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INTRODUCTION

The general current system and the distribution of the various water masses in the Norwegian Sea were first described in detail by Helland-Hansen and Nansen (1909).

Hansen (1936) published a paper on the current conditions in the Barents Sea (based on dynamic calculation). Several other papers have been published on the hydrography of both areas.

Since 1950 extensive investigations have been carried out by the Directorate of Fisheries, Institute of Marine Research, Bergen, both in the Norwegian Sea and in the Barents Sea. The Norwegian coastal waters have also been surveyed for a number of years. Most of the material has not been published, but my colleagues Dr. J. Eggvin and Mr. L. Midttun have kindly placed information at my disposal and I am greatly indebted to them for this valuable assistance.

The material used in the present paper was collected during a cruise with the R/V «G. O. Sars» in July—August 1957, as a part of an investigation on small and fat herring. In addition to hydrographic data, samples of zooplankton and fish fry were collected on each station while at selected stations fishing for small and fat herring was carried out. A preliminary report has been published by Dragesund and Ljøen (1958); the zooplankton and fish fry have been dealt with by Wiborg (1960).

The research described was intended to give a general view of the geographical distribution of the water masses in which these biological investigations were simultaneously undertaken.

THE DATA

The area investigated is shown in Fig. 1. At the serial stations observations were made to the bottom, or to 1000 m except for the stations 425—536 where the maximum depth of the observations was 250 m. At all these stations the temperature was measured and samples for

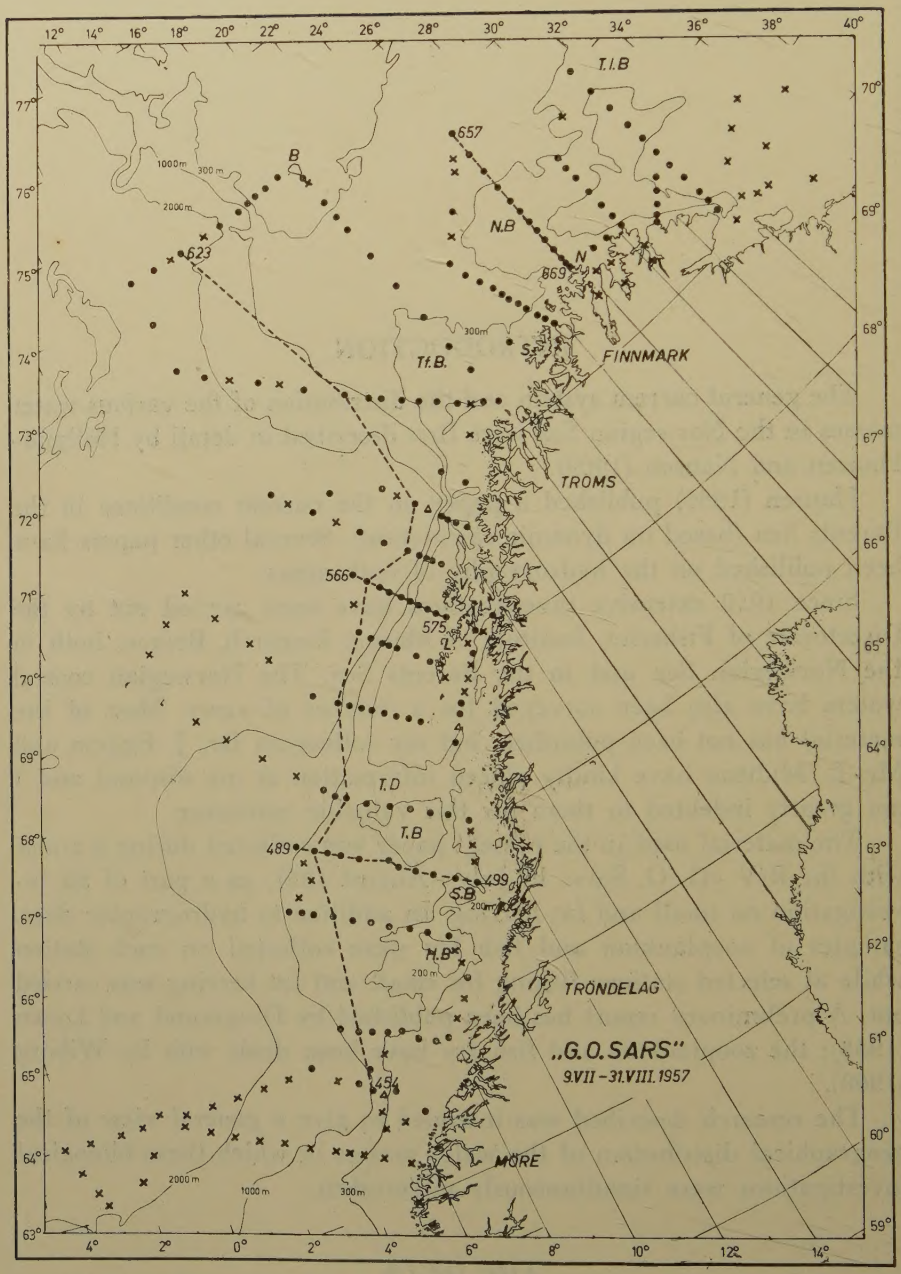

Fig. 1. Bathymetric features and location of stations. Depths in decametres. Broken lines: sections discussed in the text. T.I.B.: Thor Iversen Bank, B.: Bear Island, N.B.: North Cape Bank, Tf.B.: Tromsøflaket Bank, V.: Vesterålen, L.: Lofoten, T.D.: Træna Deep, T.B.: Træna Bank, H.B.: Halten Bank.

salinity determination collected at standard depths by means of Nansen water bottles equipped with two protected reversing thermometers. At the bathythermograph (BT) stations recordings were made to a maximum of 270 m, and surface samples taken for salinity determination.

The salinity was determined by the usual method of chloride titration. The precision of the salinity and the temperature determination was generally $\pm$ 0.02 ‰ and $\pm$ 0.02°C respectively. The σ_t and $10^5 \Delta\alpha$ values of all the temperature-salinity pairs were computed by means of a Sund slide rule (Sund 1929), the dynamic depth anomaly 10^4 ΔD being calculated by numerical integration.

Temperature-salinity curves have been prepared for each serial station. In some cases where the observations were incomplete the t—S curvees have been used for interpolation of temperature or salinity at standard depths.

The observations will be listed in Bulletin Hydrographique.

THE WATER MASSES

Water masses are usually classified on the basis of their temperature and salinity characteristics and may be studied by the aid of a t—S diagram. (Helland-Hansen 1916).

In the area studied two major types of t—S relationship could be distinguished. In the Lofoten and Vesterålen area the salinity of the water masses over the continental shelf increased from the sea surface to the bottom, while the temperature had a minimum value at some intermediate depth. This gave rise to a t—S relationship of the type shown in Fig. 2 a. Outside the edge of the shelf a salinity maximum occurred at some intermediate depth whereas the temperature gradually decreased from the sea surface to 1000 m. The corresponding t—S relationship is shown in Fig. 2 b. The stations here were chosen because they were located in the middle of the investigated area, and also because in this area the horizontal transition between water masses of different origin is sudden.

Different water masses are often delimited by certain values of salinity and temperature and give a characteristic curve in the t—S diagram. Under the influence of certain processes, for instance thermal radiation, evaporation, precipitation and mixing, the properties of the water are altered and the t—S curve may be altered. Such changes occur especially in the top layer because of climatic conditions. This is clearly demonstrated in Fig. 2 a and c which shows the summer- and winter-conditions in the water over the shelf respectively.

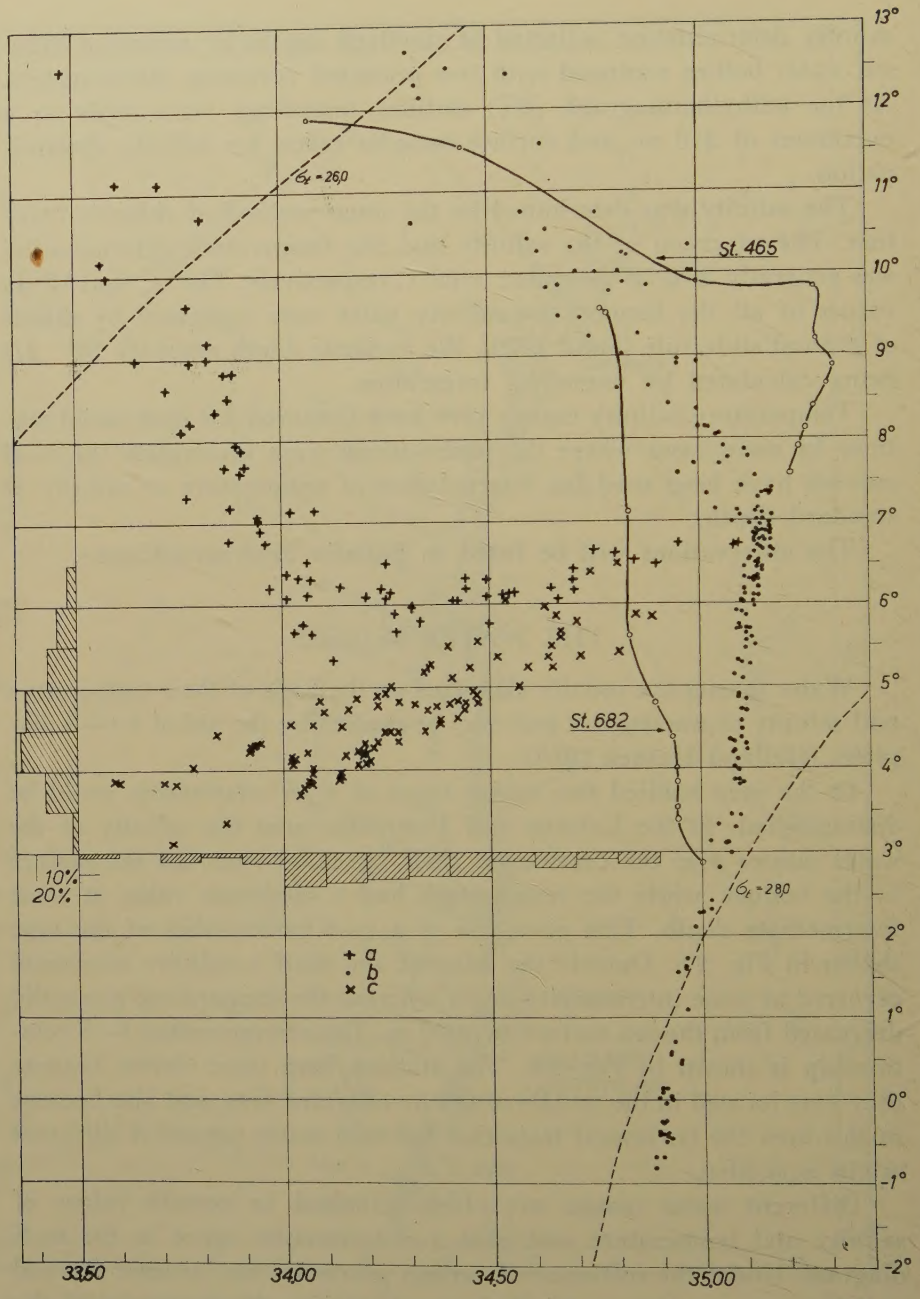

Fig. 2 a) t—S pairs of water masses inside the edge of the shelf off Lofoten and Vesterålen. b) t—S pairs of water masses outside the edge of the same shelf. c) t—S pairs of water masses at the fixed oceanographical station off Eggum.

The fixed oceanographical station off Eggum, Vesterålen is situated above the shelf in the water masses mentioned before. The t—S relationship from this station demonstrates a winter situation. (The observations were taken in March and April during the years 1951—1955 and 1957). In the deep layers (highest salinity) the condition in July—August was similar to that in the winter. A great change in temperature, about 9°C, was found at the surface (lowest salinity), and it is clearly shown in the figure that the intermediate temperature minimum found in July—August was due to the winter cooling.

All the (t—S)-points from the winter observations in the water inside the edge of the shelf (Fig. 2 c) at temperature intervals of 0.50°C and salinity intervals of 0.10 ‰ horisontally and vertically respectively have been collected. The frequency distribution of temperature and salinity is shown by the histogram in Fig. 2.

Most of the salinity values fell between 34.00 ‰ and 34.50 ‰. The values above 34.50 ‰ were mainly observed at 150 and 300 m.

The condition at this station was representative of most of the water masses inside the edge of the shelf in this area and, as shown in Fig. 5 B, the 34.50 ‰ isohaline at a depth of 50 m ran more parallel to the coast than did the 35.00 ‰ isohaline, especially in the Barents Sea Area. The present author has therefore found it practical to define coastal water as water masses with salinity 34.50 ‰ or below, while waters with salinity 35.00 ‰ or higher are characterized as Atlantic water according to Helland-Hansen and Nansen (1909).

A t—S relationship similar to the one shown in Fig. 2 a was typical of the water in a zone along the main part of the coast.

The stations off the shelf were located in the Norwegian Atlantic Current. St. 465 was taken in this current outside Trøndelag when the core of Atlantic water had a salinity above 35.3 ‰ with a corresponding temperature of 9°C. These figures are close to those which, according to Jacobsen (1943), characterize the pure Atlantic water in the Faroe—Shetland channel ($S = 35.45$ ‰, $t = 10.2$°C).

In the figure it is clearly shown that the Atlantic water, forming the Norwegian Atlantic Current, on its way from the Atlantic Ocean was mixed with water masses of lower salinity until it reached the condition found at st. 682. This station was situated 170 n. m. north of Vardø where intensive mixing takes place between the water of the North Cape Current and the water masses of the eastern Barents Sea.

Fig. 3 shows the distribution of the water masses showing the two different t—S relationships distinguished in Fig. 2 a and b, (cp. the text of the figure). Outside Møre and Vesterålen the border between areas with these two different t—S relationships was clearly marked (Fig. 3).

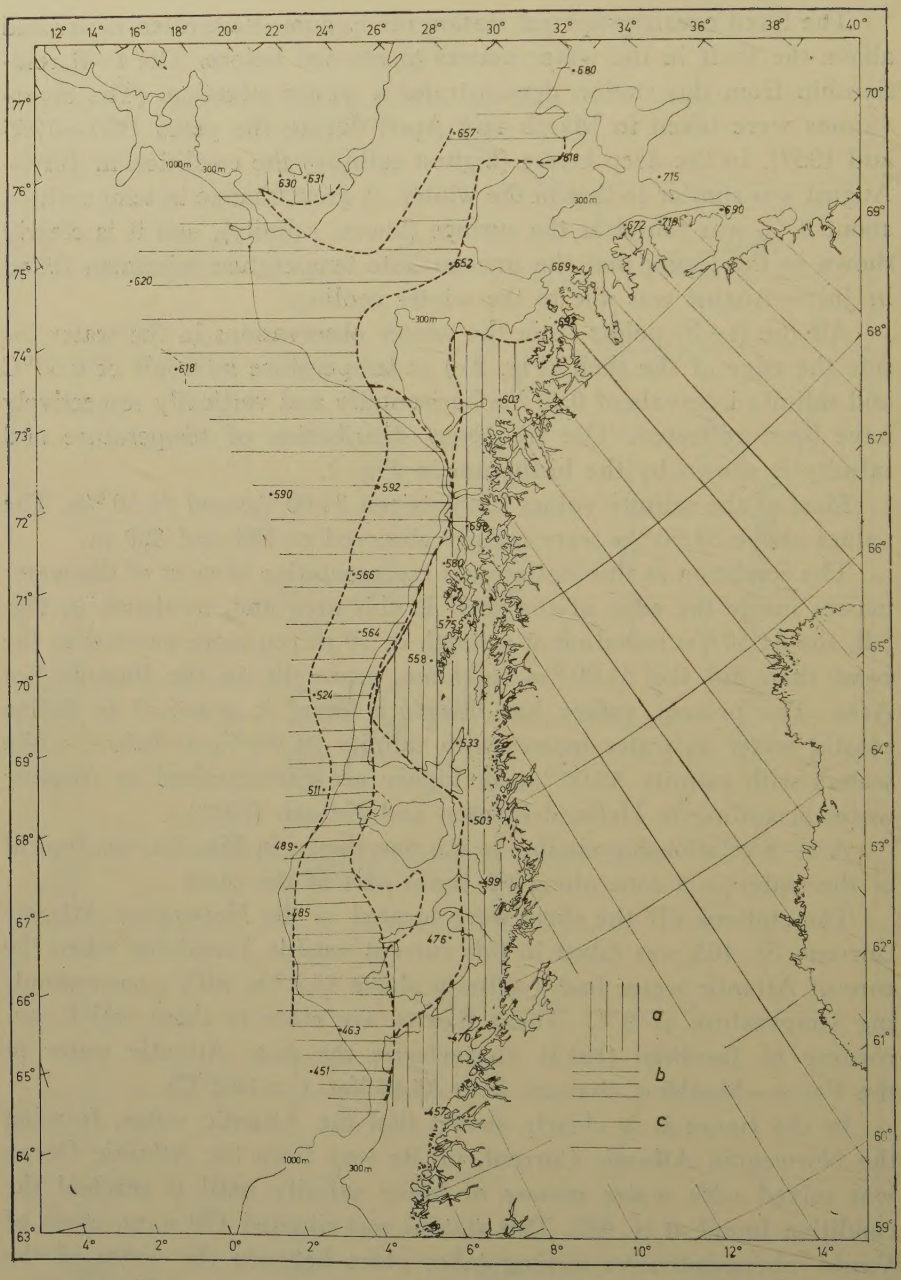

Fig. 3 a) Intermediate minimum in temperature, salinity increasing from surface to bottom or 250 m (see Fig. 2 a). b) Clearly marked intermediate maximum in salinity decreasing temperature from sea surface to the maximum depth of observation. (See Fig. 2 b). c) The same as b, the salinity maximum however being less pronounced. The first and the last station in each section are indicated by dots and a number.

The depth of the salinity maximum varied somewhat from one station to another, but as a whole it occurred between 50 and 150 m.

At the entrance to the Barents Sea the waters in the Norwegian Atlantic Current have had their characteristic t—S relationship sligthly modified, because of horizontal and vertical mixing.

Part of the Helgeland Plateau was covered by water in which the salinity increased from the surface to the bottom or 250 m. With the exception of the upper 30 m, the salinity was above 35.00 ‰, while the temperature usually decreased downwards. Off Finnmark the conditions were similar, although the salinity was lower on the average.

HORIZONTAL DISTRIBUTION OF TEMPERATURE, SALINITY AND DENSITY

In order to study the horizontal distribution of temperature, salinity and density, the standard depths, 0 m, 50 m, 100 m, and in addition 1000 m in the north-western part of the area have been selected.

0 m. (Fig. 4 A—C)

Off western Norway the highest temperature, above 12°C, was found close to the coast, whereas off the coast between Vesterålen and Vardø the temperature was below 10°C, the maximum temperature being at a distance of 25—50 n. miles offshore.

A tongue of warm, low density coastal water extended from the southernmost region along the edge of the shelf, reaching 66° N. This tongue was only observed at 0 and 10 m.

In the Norwegian Atlantic Current the maximum salinity observed was 35.3 ‰ corresponding to a temperature of 11.5°C. Both salinity and temperature decreased westwards to 35.0 ‰ and 8.4°C respectively in the East Icelandic Arctic Current, about 100 n. miles northwest of the Faroe Island.

The 34.0 and 34.5 ‰ isohalines together with the σ_t lines ran approximately parallel to the depth contours around Tromsøflaket. The current system in this region will be discussed later on.

Off the entrances of Laksefjord, Porsangerfjord and Tanafjord the zone of cold coastal water extended further out, partly because of the outflow of water from these fjords.

Farther to the east, where the North Cape Current meets water of more or less Arctic origin, the isolines mainly ran from north to south.

On entering the Barents Sea the Atlantic water had a temperature

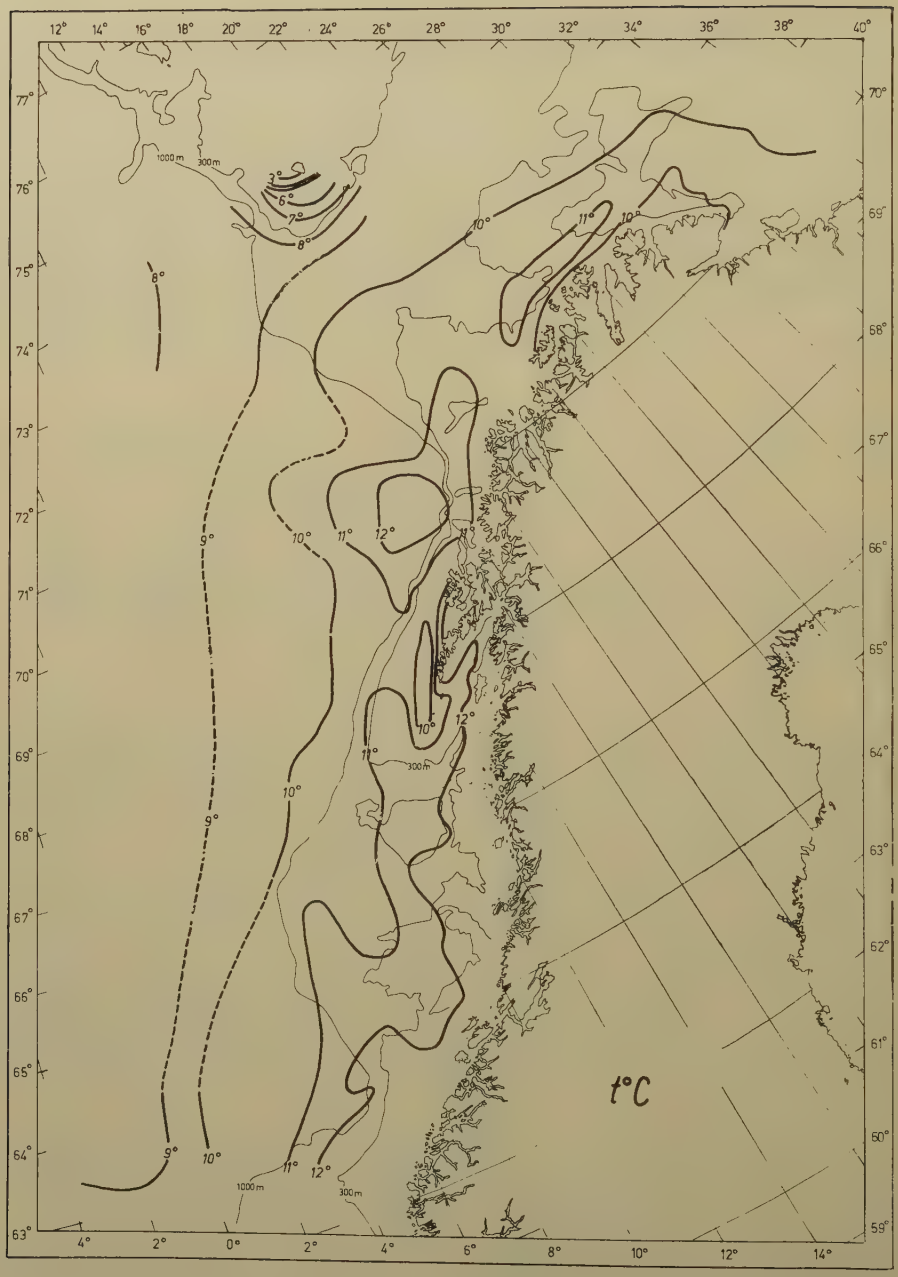

Fig. 4. A) Temperature at the sea surface.

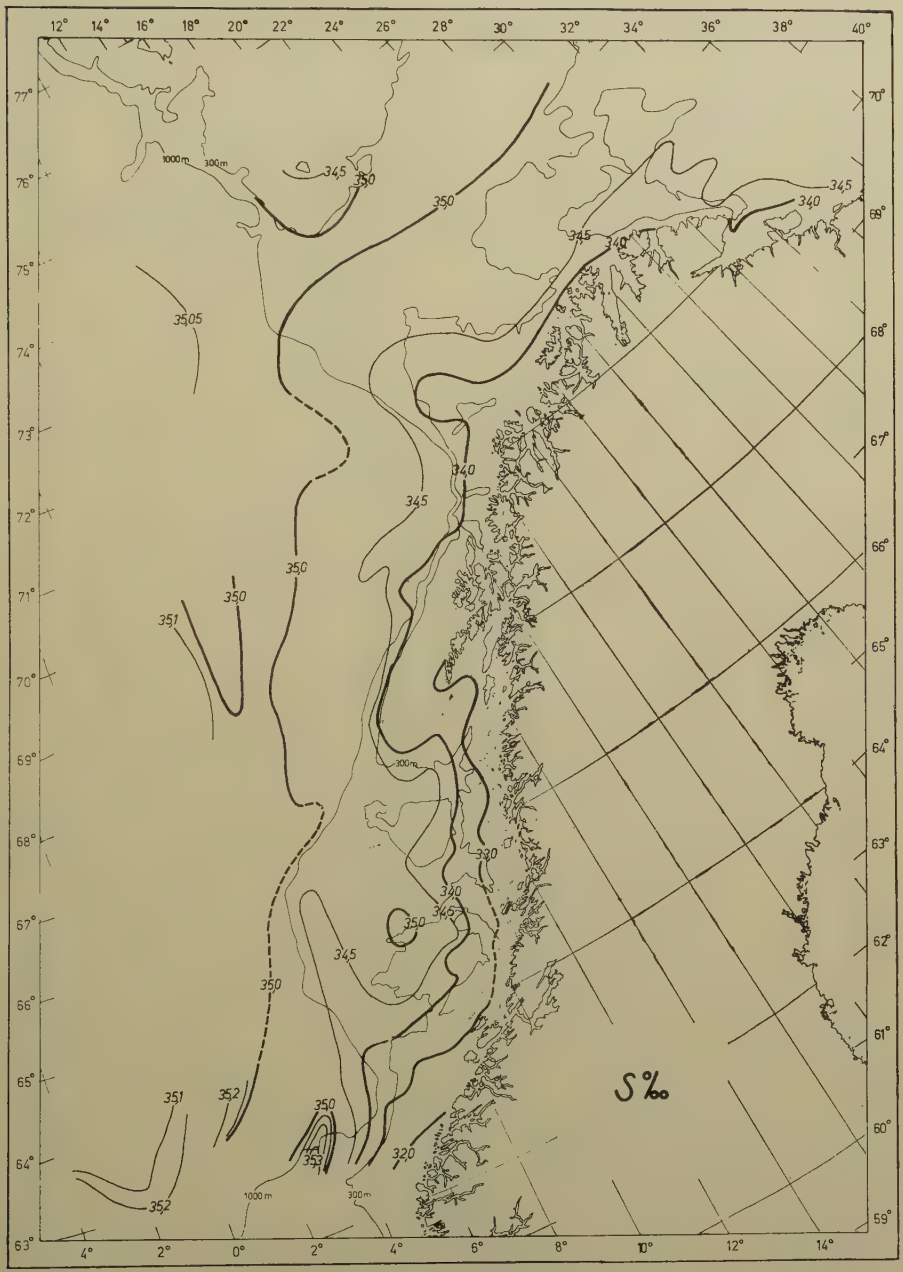

Fig. 4. B) Salinity at the sea surface.

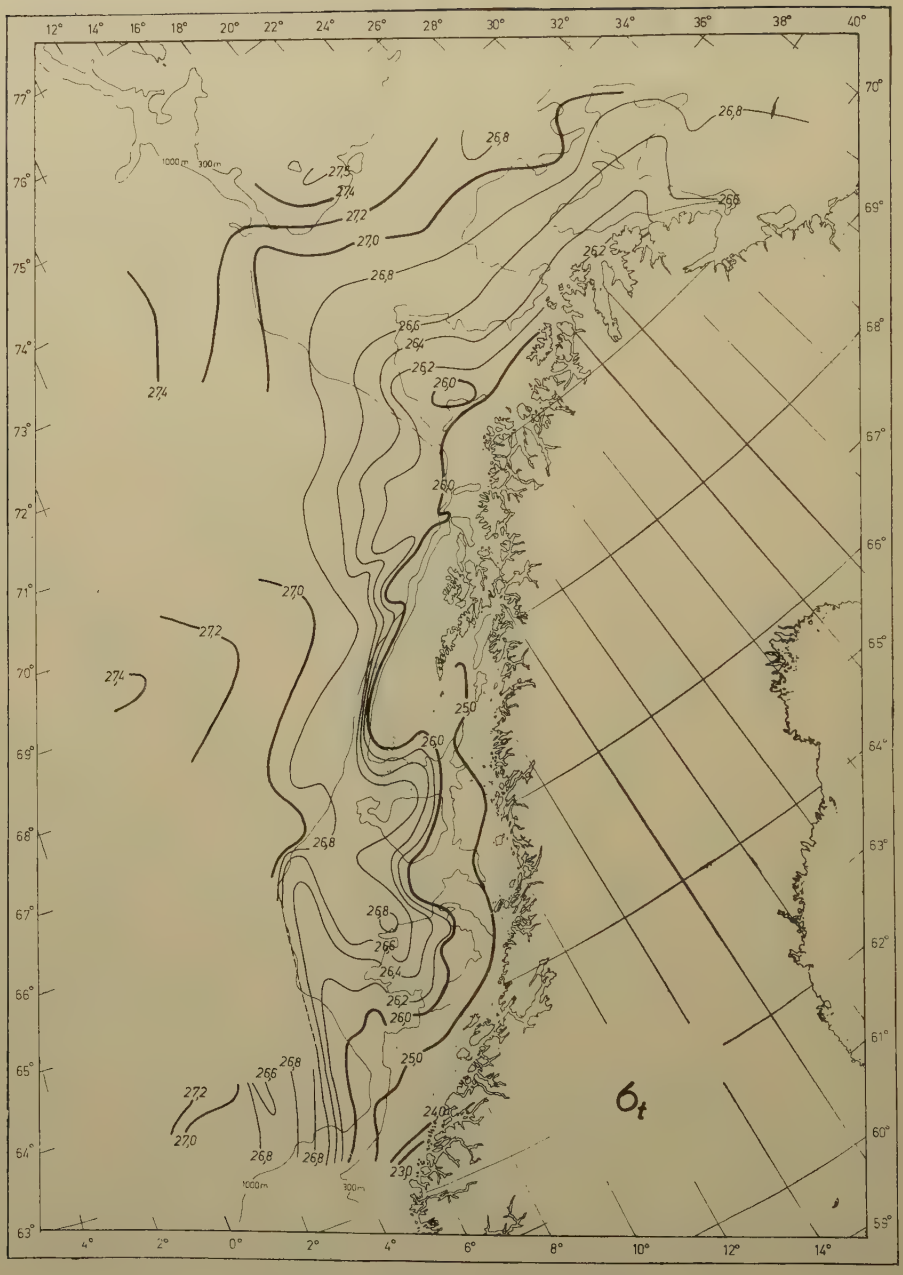

Fig. 4. C) Density at the sea surface.

of 9—10°C. In the Bear Island Current the salinity and temperature decreased to 34.2 ‰ and 2.4°C respectively.

Defining the convection layer as the layer within which the density differs by less than 0.1 in σ from the density at the surface, we found that the thickness of the convection layer was mostly less than 20 m, except close to the Bear Island where it was about 50 m.

The distribution of the average salinity and temperature of the upper 10 m did not differ from that of the surface.

50 m. (Fig. 5 A—C)

The temperature of the coastal water between Rundø and Ytterholmen was 7—8°C, between Ytterholmen and Sørøy 6—7°C. Farther to the east the temperature was again above 7°C. In the fjords of northern Norway the temperature decreased in an inward direction.

The density of the coastal water was less than 27.2 in σ_t.

In the investigated area, the Atlantic water had in the main a tongue-like distribution of salinity, temperature and density.

A tongue of relatively high temperature and salinity stretched to the north from outside Møre to the entrance of the Barents Sea. A high salinity was usually accompanied by a high temperature. The maximum figures, above 35.3 ‰ and 10°C, were found in the southernmost area. Owing to mixing from both sides with water masses of lower salinity and temperature, the core of the tongue gradually grew colder and less saline towards the north, being 7.0°C and 35.15 ‰ respectively off Vesterålen. In the southern part the axis of the tongue followed the edge of the shelf, whereas outside Lofoten and Vesterålen it was found at some distance off the continental slope.

A tongue of relatively saline (above 35.1 ‰) and warm (above 7° C) Atlantic water pushed towards the coast between the Halten and Træna banks, another tongue of somewhat lower salinity (35.0—35.1 ‰) and temperature (below 7°C) stretched from the coast to the southwest across the Træna bank.

In the southernmost part of the area a third tongue of water along the continental slope had a density between 27.2 and 27.4 in σ_t up to the Træna deep, being flanked on both sides by heavier water (σ_t 27.4—27.5).

As is known, the Norwegian Atlantic Current branches at the entrance of the Barents Sea. One branch continues to the north along the west side of the Bear Island, another turns to the east into the Barents Sea. Between the last mentioned branch and the coastal water a tongue of heavy (σ_t above 27.6) and relatively cold (5—6°C) water of salinity 34.9—35.05 ‰ was directed westwards, reaching 22° E.

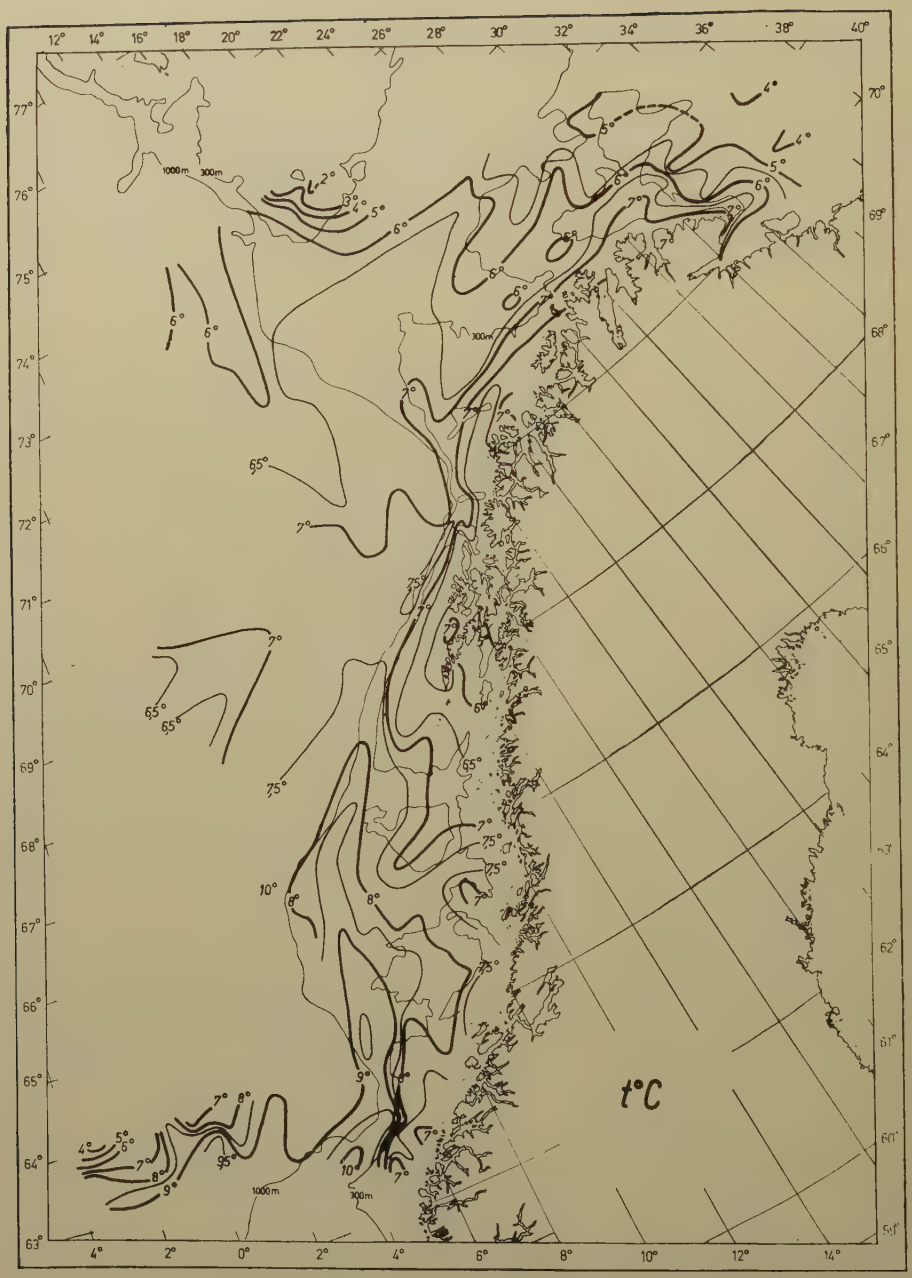

Fig. 5. A) Temperature at 50 m.

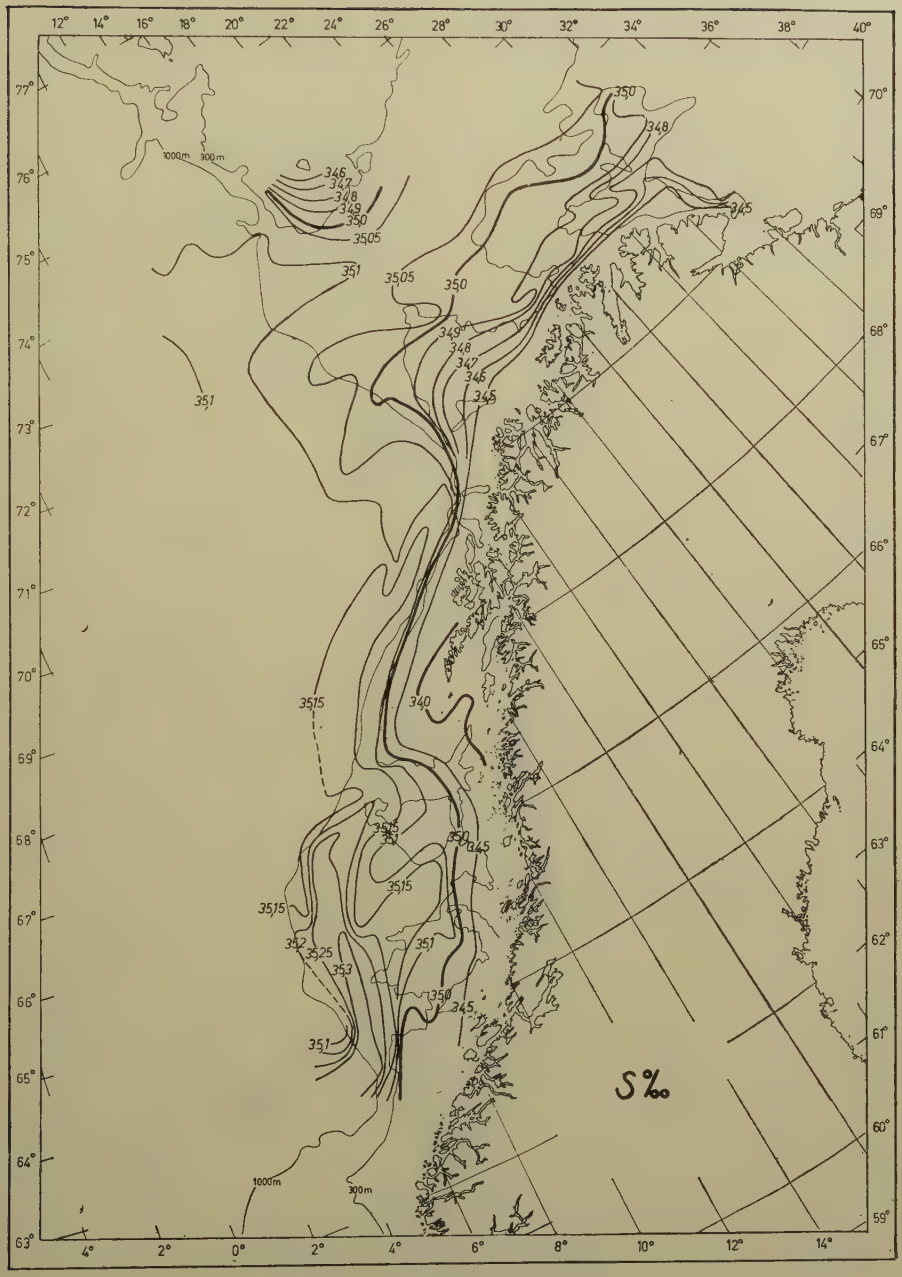

Fig. 5. B) Salinity at 50 m.

Fig. 5. C) Density at 50 m.

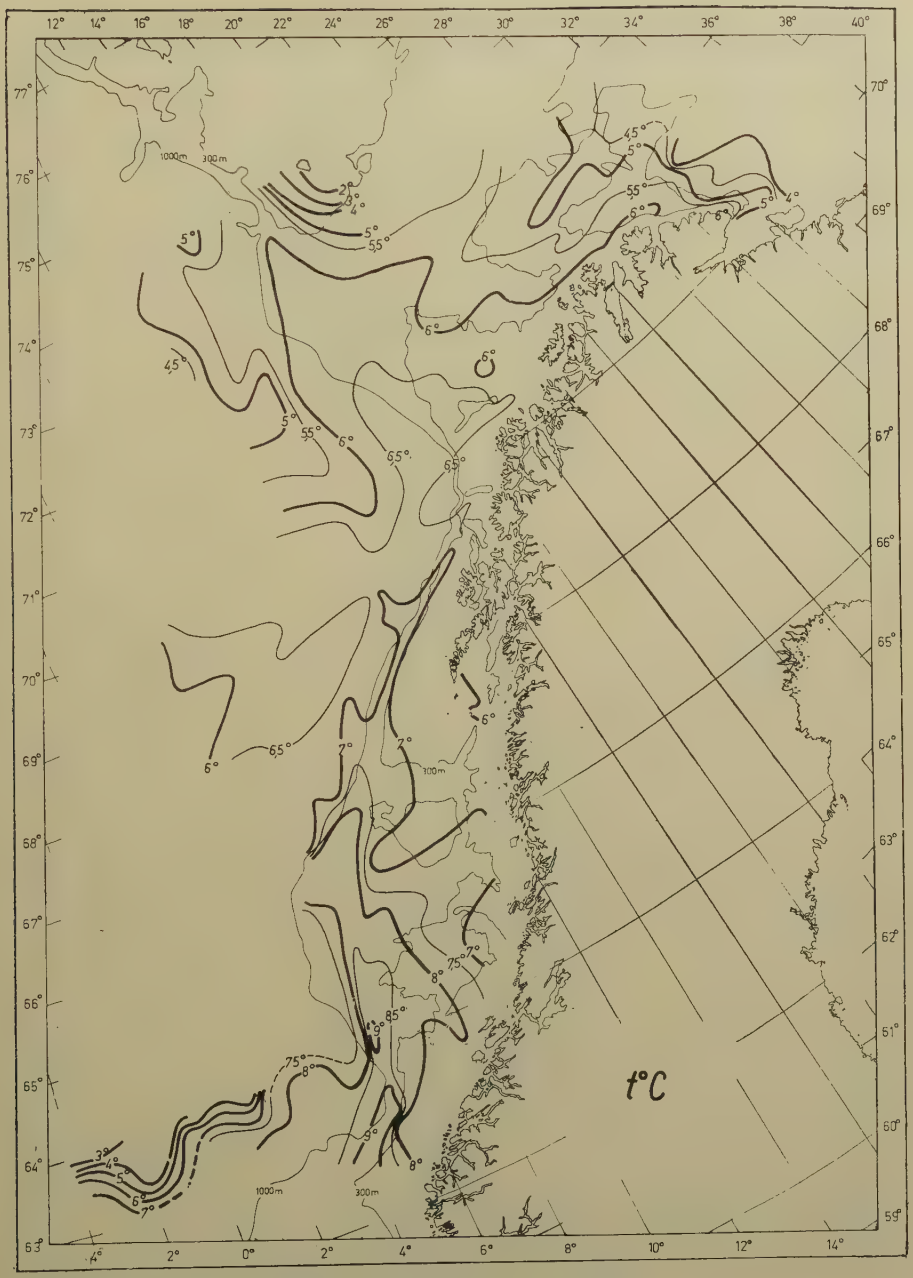

Fig. 6 A) Temperature at 100 m.

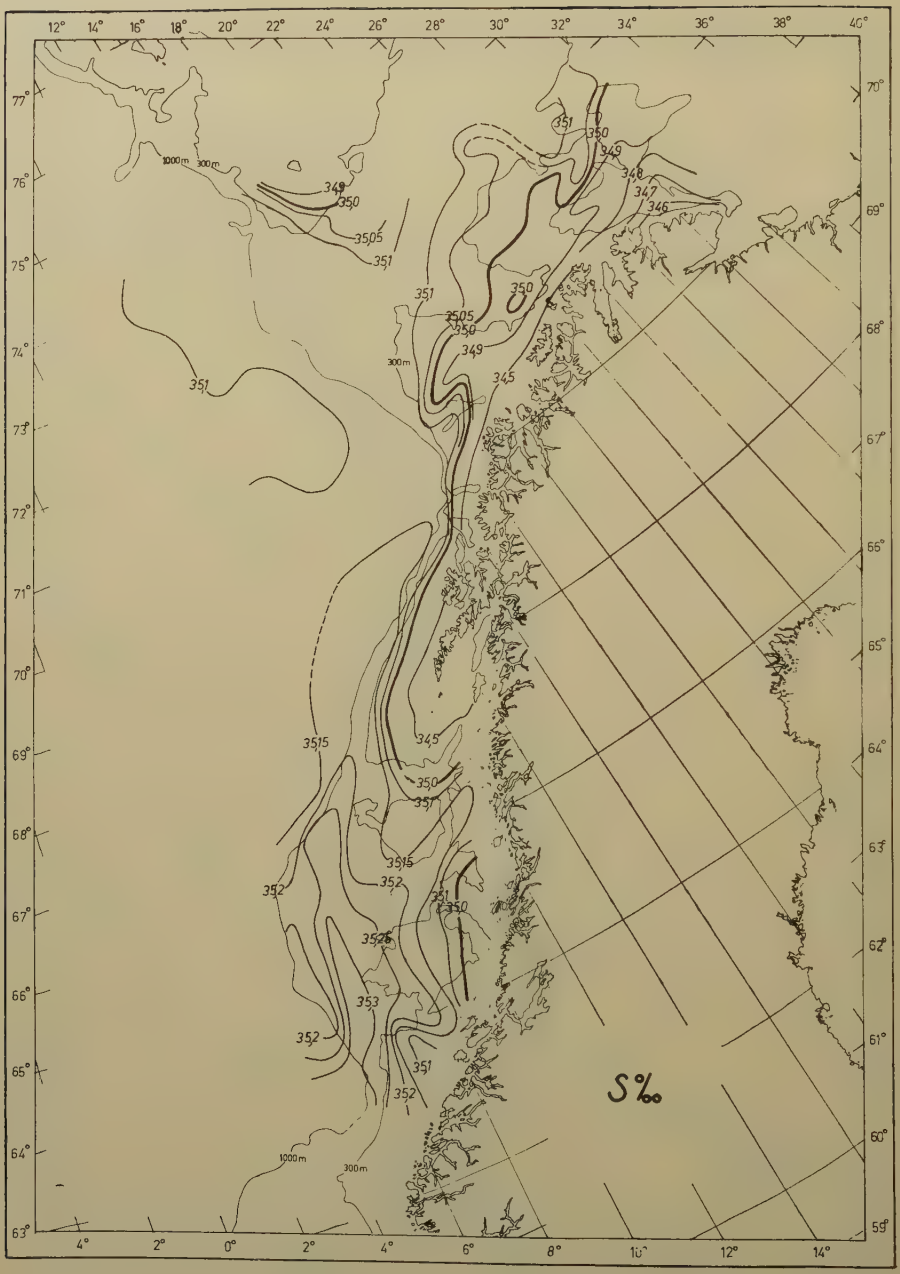

Fig. 6 B) Salinity at 100 m.

Fig. 6. C) Density at 100 m.

Fig. 7. Temperature at 1000 m.

100 m (Fig. 6 A—C)

At this depth the relative distribution of properties of the water masses was similar to that at 50 m. Both in the Atlantic and coastal waters however, the temperature was 0.5—1.0°C lower, and the density somewhat higher.

1000 m (Fig. 7)

At this depth the water was approximately homohaline, with a salinity of 34.89—34.93 ‰.

The coldest water was found close to the continental slope with minimum temperatures of ÷ 0.97° and ÷ 0.96°C respectively at st. 626 west of the Bear Island, and st. 562 off Moskenes Island. Mosby (1959, p. 18, Fig. 10) found a similar temperature distribution between the North Sea Plateau and 67° N and we may assume that the temperature distribution shown in Fig. 7 is characteristic of the eastern side of the Norwegian Sea.

Some of the salinity figures in the deep water, especially from the area with minimum temperature were remarkably low, 34.89 and 34.90 ‰. However, all these samples were analysed several times, the result being within the precision of the titration.

VERTICAL DISTRIBUTION OF TEMPERATURE, SALINITY AND DENSITY

In order to characterize the vertical stratification of the water masses four sections have been selected: 1) across the Helgeland Plateau, st.s. 489—499. 2) outside Vesterålen, st.s. 566—575. 3) from North Cape to the north, st.s. 657—669. and 4) along the core of Atlantic Water (maximum of salinity) (See Fig. 1).

All the observed and calculated properties here discussed have also been studied in the other sections, but the four sections mentioned were found to be representative of the vertical distribution of the water masses in the area investigated.

The Helgeland Section (Fig. 8)

A core of Atlantic water, with a salinity above 35.30 ‰ was found at a depth of 75 m at the edge of the shelf about 100 n. miles off the Sklinna Bank. The corresponding temperature was 8.6°C and the density 27.45—27.47 in σ_t.

Another core with a maximum salinity of 35.2 ‰ and temperature above 7°C occurred immediately off the Sklinna Bank.

These cores were those of the two horizontal tongues of high salinity discussed on page 15, and were separated by less saline Atlantic water.

Along the whole section the temperature in the upper 20—30 m layer was above 9°C, while the salinity was below 35.0 ‰, except at the outermost station.

At the two innermost stations water with salinity below 35.0 ‰ was found down to about 100 m, and an intermediate temperature minimum, caused by the winter cooling, was observed in the same locality between 50 and 100 m.

The Vesterålen Section (Fig. 9)

In the uppermost 10 m warm coastal water (above 10°C) was found to a distance of about 35 n. m. outside the shelf.

In the shallow part of the section the temperature minimum at 75 m was a result of the winter cooling. The shelf was covered by water of a salinity below 35.0 ‰. In the section to the south of this, where the depth is somewhat greater (about) 150 m), Atlantic water was present immediately above the bottom.

As shown earlier, (page 7) the temperature off the shelf descreased from the sea surface to 1000 m, the salinity maximum mentioned being found at a depth of about 150 m. Vertical temperature gradients have been calculated for four temperature intervals in the section: above 8°C,

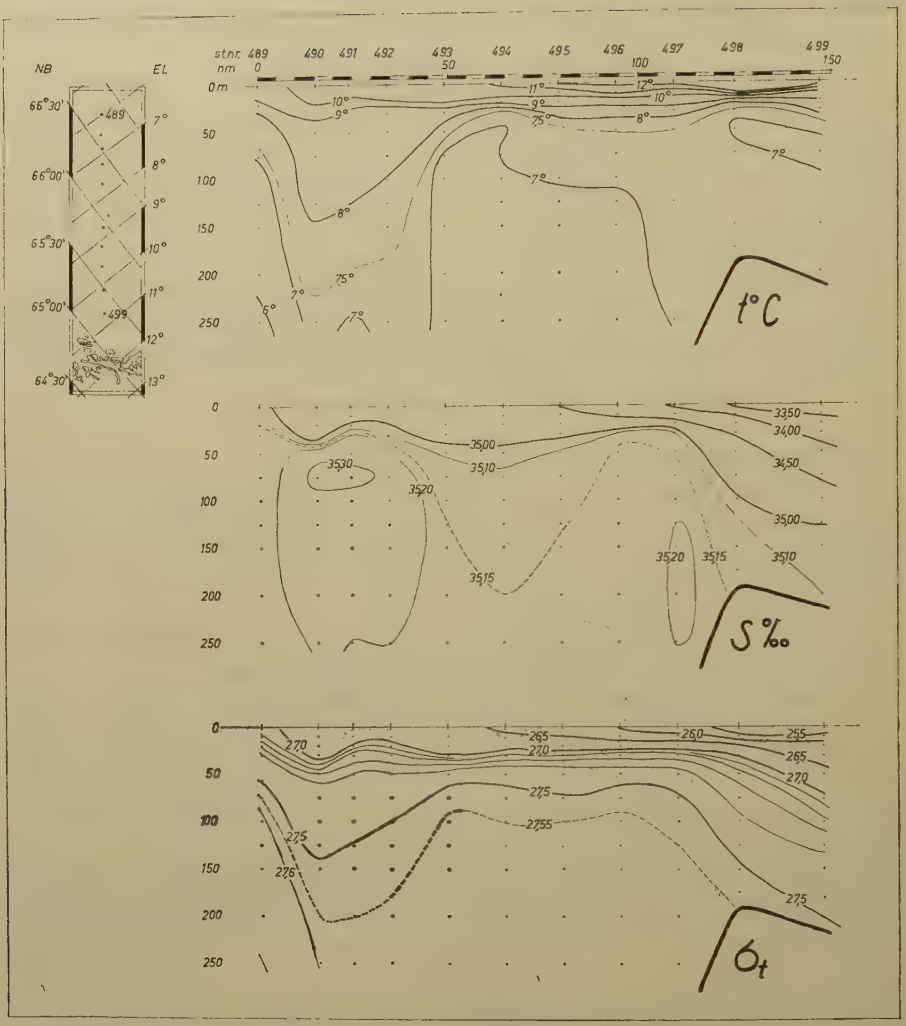

Fig. 8. Temperature, salinity and density in section across the Helgeland Plateau.

4—8°C, 1—4°C and below 1°C. The values are mean figures based on the conditions at the five outer stations. The various water masses are associated with gradients of a certain magnitude. In Fig. 9, the 8° isotherm approximately coincides with the upper 35.0 ‰ isohaline beyond the edge of the shelf. In the water masses above these isolines the temperature gradient was $105.3 \cdot 10^{-3}$ degr. C/m. In the range 4—8°C, where Atlantic water was found, the gradient was $8.0 \cdot 10^{-3}$ degr. C/m. This water mass was separated from the deep water by a transition layer with a temperature gradient of $15.3 \cdot 10^{-3}$ degr. C/m. In its broad features the 1° isotherm followed the 34.95 ‰ isohaline,

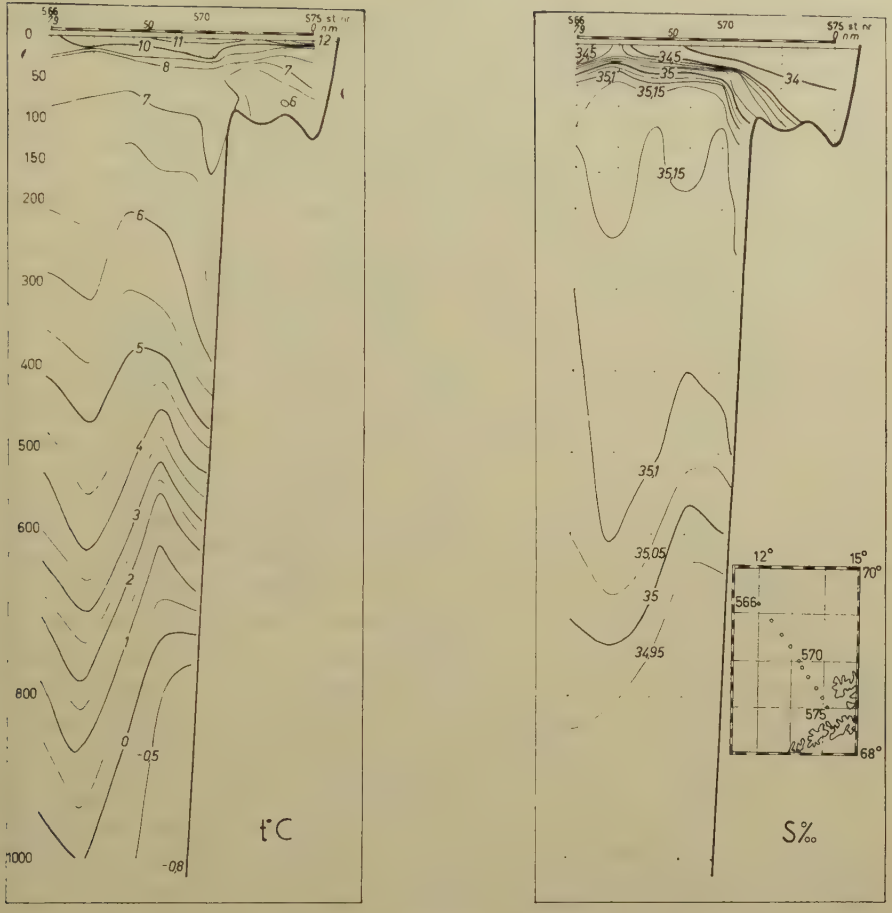

Fig. 9. A) Temperature, B) salinity in a section off Vesterålen.

and in the water mass below, the deep water, the temperature gradient was $5.6 \cdot 10^{-3}$ degr. C/m.

Such a relatively strong gradient in the transition layer seems to be in good accordance with the conditions in a section across the continental slope outside the Sognefjord described by Sælen (1959). Our section was too short to demonstrate a convergence of isolines when approaching the slope similar to that found in the Sognefjord section (Sælen 1959, page 24). However, investigations made by the Directorate of Fisheries, Institute of Marine Research, Bergen, in the summers of the years 1954—1960 indicated that the convergence mentioned usually appears in this region (unpublished data).

Another feature common to the Vesterålen and Sognefjord sections was the distribution of the cold deep water. In both localities this water

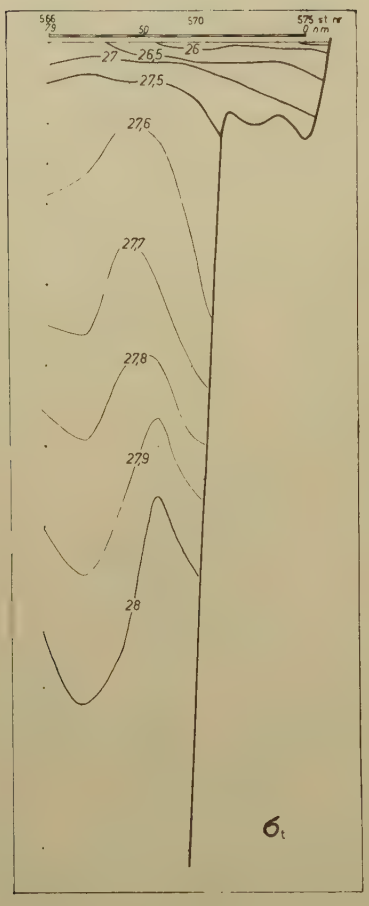

Fig. 9. C) Density in a section off Vesterålen.

ascended along the slope. As is evident from Fig. 9, a temperature below -0.5° C was observed at 800 m at st. 570 whereas at the stations further offshore low temperatures were not found down to a depth of 1000 m.

As previously mentioned (page 22) the lowest temperatures in the water masses at 1000 m were always found along the slope. This distribution of temperature indicates that conditions similar to that described above were present all along the slope in the north-western part of the investigated area.

The mechanism for maintaining this distribution of temperature is possibly the same as has been assumed for the Sognefjord section (cp. Sælen 1959, page 24). One might also assume that the relatively strong temperature gradient in the transition layer between Atlantic and deep waters was partly caused by deep water moving up the slope.

The North Cape Section (Fig. 10)

In order to characterize the stratification of the various water masses in the part of the Barents Sea investigated, the North Cape section has been selected.

Along the whole section the temperature in the upper 10—20 m layer was above 9°C.

Coastal water was found in a narrow zone close to the coast, while only to the north of the North Cape Bank did Atlantic water come to the surface. The temperature in the Atlantic water mass was mostly below 5.5°C except in the upper 50 m of the area north of the North Cape Bank.

Owing to intensive mixing between Atlantic and coastal water masses off Troms, there was a greater quantity of mixed water in this section than in the other two sections discussed above.

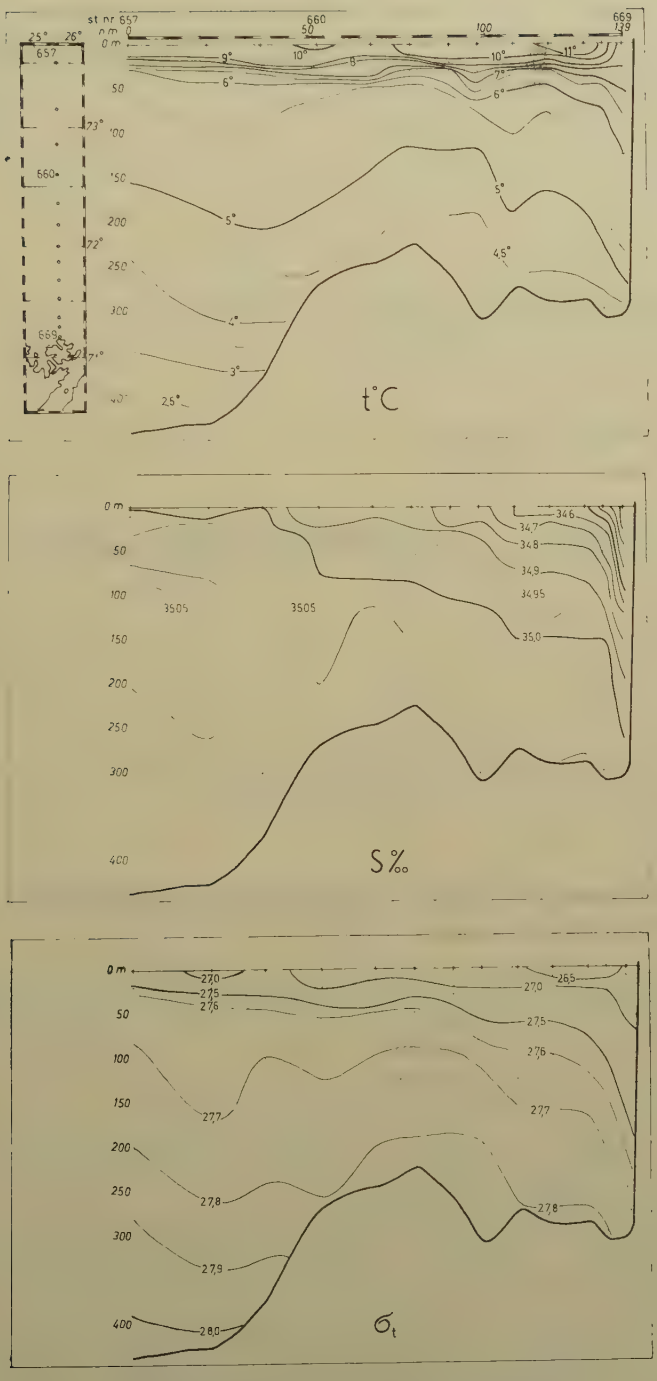

Fig. 10. Temperature, salinity and density in a section from North Cape to the north.

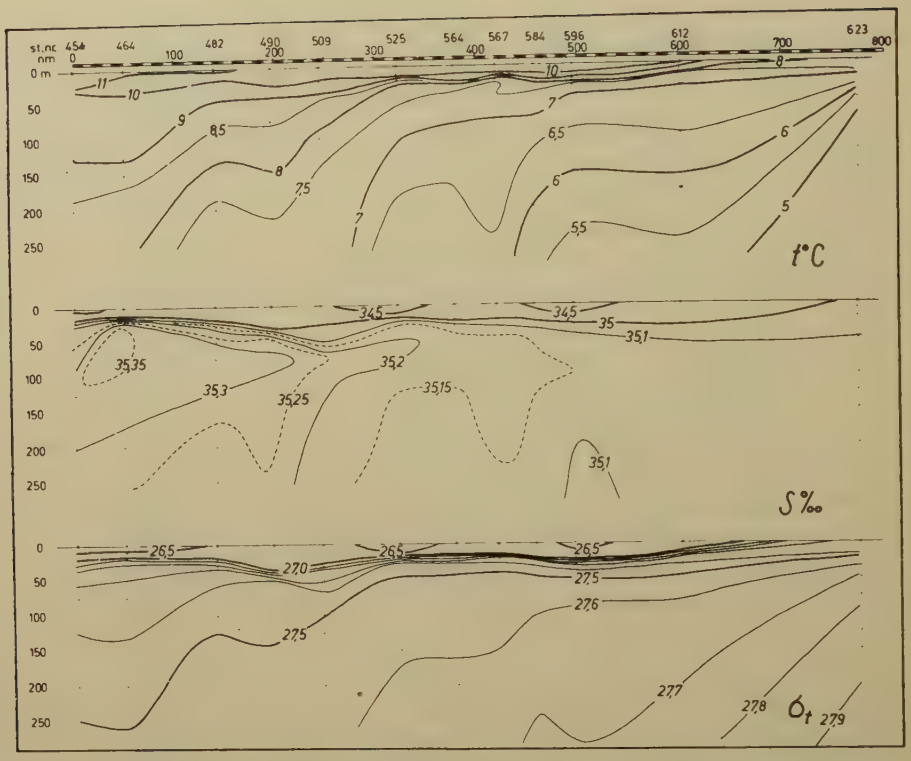

Fig. 11. Temperature, salinity and density in a section along the core of Atlantic water (maximum salinity).

The Section along the Core of Atlantic Water (Maximum of Salinity) (Figs. 11 and 12)

Apart from the surface layer, the salinity of which is below 35.0 ‰, there was on the average a decrease in salinity and temperature, and a rise in density from the south to the north. The horizontal gradients in the properties mentioned were conspicuous off the Træna Deep (between st.s 509 and 525), especially below the salinity maximum. From the Træna Deeep to Andenes (st. 596) the conditions were more uniform, while further northwards the salinity was relatively constant although since the temperature steadily decreased, especially below 100 m. The variation in the core of the Atlantic water is shown in Fig. 12. The purest Atlantic water was found at st. 464. Between this station and st. 596 there was a quasi-linear decrease in temperature and salinity but at the latter station the t—S curve took a sudden bend. In addition to the distribution of properties in the section (Fig. 11) the course of the t—S curve clearly shows that the water masses across the

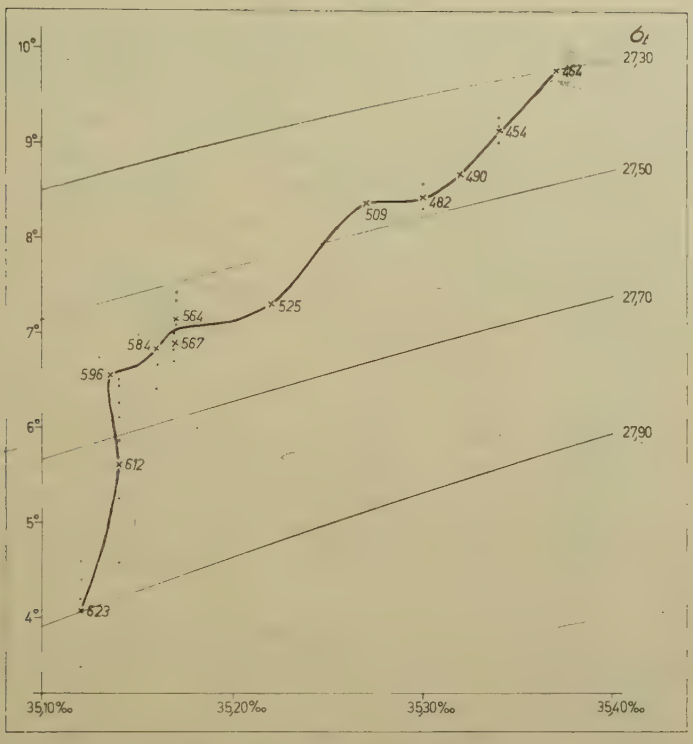

Fig. 12. t—S-relation from the layer of the core of Atlantic water in the section shown in Fig. 11.

entrance to the Barents Sea (between st.s 596 and 623) were thoroughly mixed with heavier water which probably originated from the central part of the Norwegian Sea.

The water masses at the entrance are the source of Atlantic water in the Barents Sea.

THE MOVEMENT OF THE WATER MASSES

So far the vertical and horizontal distributions of salinity, temperature and density have been discussed. The inner field of mass has been obtained from this distribution, allowing the computation of the relative field of pressure, characterized by $\Delta D = \int_{p}^{p_0} \Delta\alpha \, dp$ (Sverdrup, *et al.* 1957). $\Delta\alpha$ is the anomaly of specific volume and ΔD the geopotential anomaly between the isobaric surfaces p and p_0. By using these quanti-

ties in the formula $v - v_0 = \frac{\Delta D_A - \Delta D_B}{L \cdot 2\omega \sin\varphi}$ derived at by Helland-Hansen (1905), the current velocity v in the isobaric surface p relative to the velocity v_0 in the isobaric surface p_0 can be computed. L means the horizontal distance between the stations A and B, ω angular velocity of the earth and φ the geographical latitude. Velocity means the average horizontal velocity of the current component *cum sole* at right angle to the connection line A — B.

The volume transport by the relative current between the sea surface and the isobaric surface p_0 can be calculated by the formula $V_{AB} = \frac{\Delta Q_A - \Delta Q_B}{2\omega \sin\varphi}$ (Jakhelln 1936), where $\Delta Q = \int_0^{z_0} \Delta D \mathrm{dz} = \int_0^{z_0} \int_0^{P_0} \Delta\alpha \mathrm{dzdp}$. z_0 means the geometric depth of the isobaric surface p_0.

These formulae are only valid under stationary conditions.

As previously mentioned the observations were taken to the bottom or to a maximum of 1 000 m during the last part of the cruise (st.s 558—690). Based on this material currents and volume transport in this region have been discussed.

Where the reference depth is greater than the depth to the bottom the method described by Helland-Hansen (1934) for calculating the dynamic height has been used.

Owing to the great difference in depth between the Norwegian Sea and the Barents Sea the movement of the water masses may conveniently be dealt with in each area separately.

The Deep Sea (Figs. 13 and 14 A—B)

The 1 000 db surface has been used as a reference. Fig. 13 shows the distribution of $\Delta\alpha$ and the current conditions in the section off Vesterålen discussed above.

Immediately off the edge, the maximum current velocity was towards the north-east. In the uppermost 50 m this current component was found in coastal and mixed water and below this depth in the eastern part of the core of Atlantic water.

This agrees with observations by Krauss (1957) who also found a strong current component above the slope directed towards north-east, referred to the 1200 db surface in a section outside Andenes.

In the shallow part of the section the current also flowed to the north-east, the velocity however being considerably lower. About 30 n.m. off the edge of the shelf, in the central and western part of the core of Atlantic water, the current had a component to the south-west with a maximum of velocity ocurring between 20 and 200 m. To the

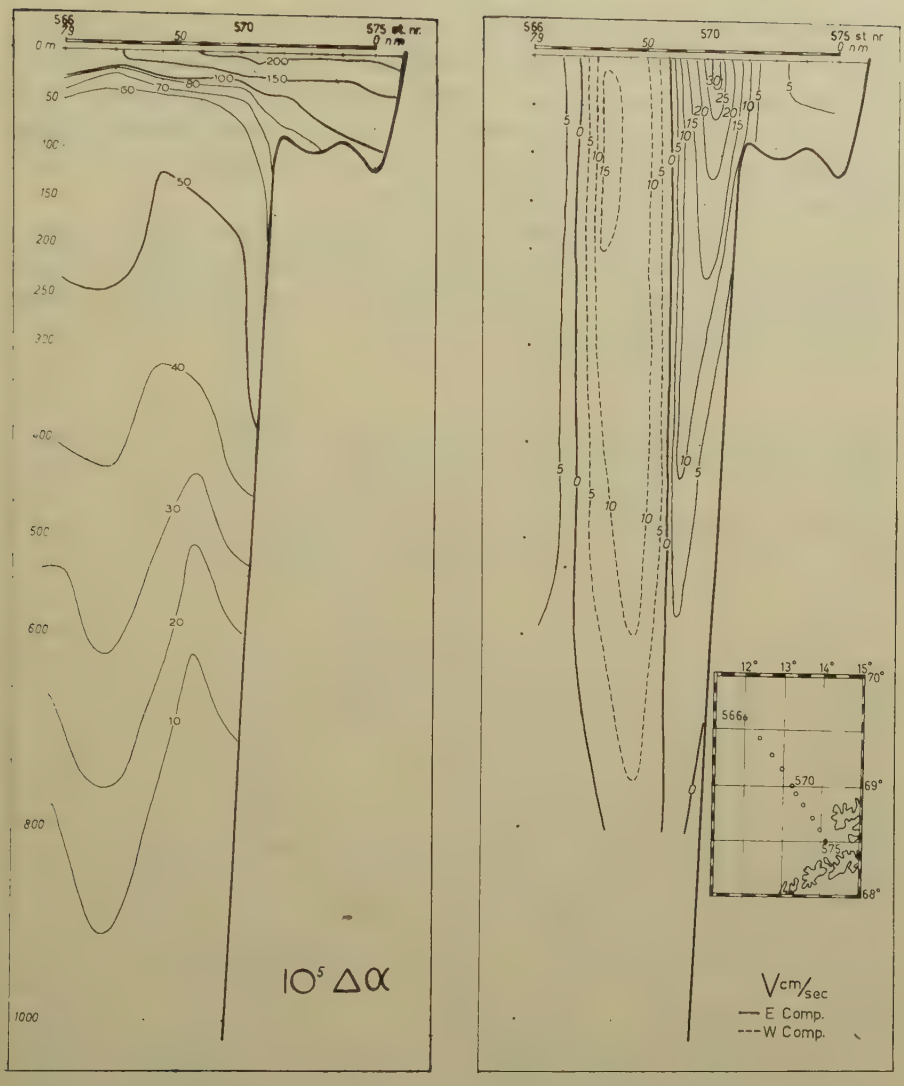

Fig. 13. Specific volume anomaly and current in the section off Vesterålen.

north-west of this branch the current is again directed towards north-east.

Fig. 14 A shows the geopotential topography of the sea surface relative to 1000 db depth. The contour lines only approximately represent stream lines (Sverdrup *et al.* 1957). The direction of the current is approximately parallel to the stream lines and the velocity is inversely proportional to the distance between the contour lines, the factor of the proprotionally depending upon the latitude.

Along the edge there was a well-defined flow to the north reaching the Bear Island Channel. In the Lofoten and Vesterålen area there was an anticyclonic movement outside this current branch. This pattern of the flow corresponded to the current distribution in the section discussed above. In the north-western part of the area investigated, both south and north-going currentbranches appeared.

In Fig. 14 B is shown the volume transport of the relative current between the sea surface and 1000 m. The curves are transport lines bearing the same relation to the relative volume transport as the curves of ΔD to the relative current.

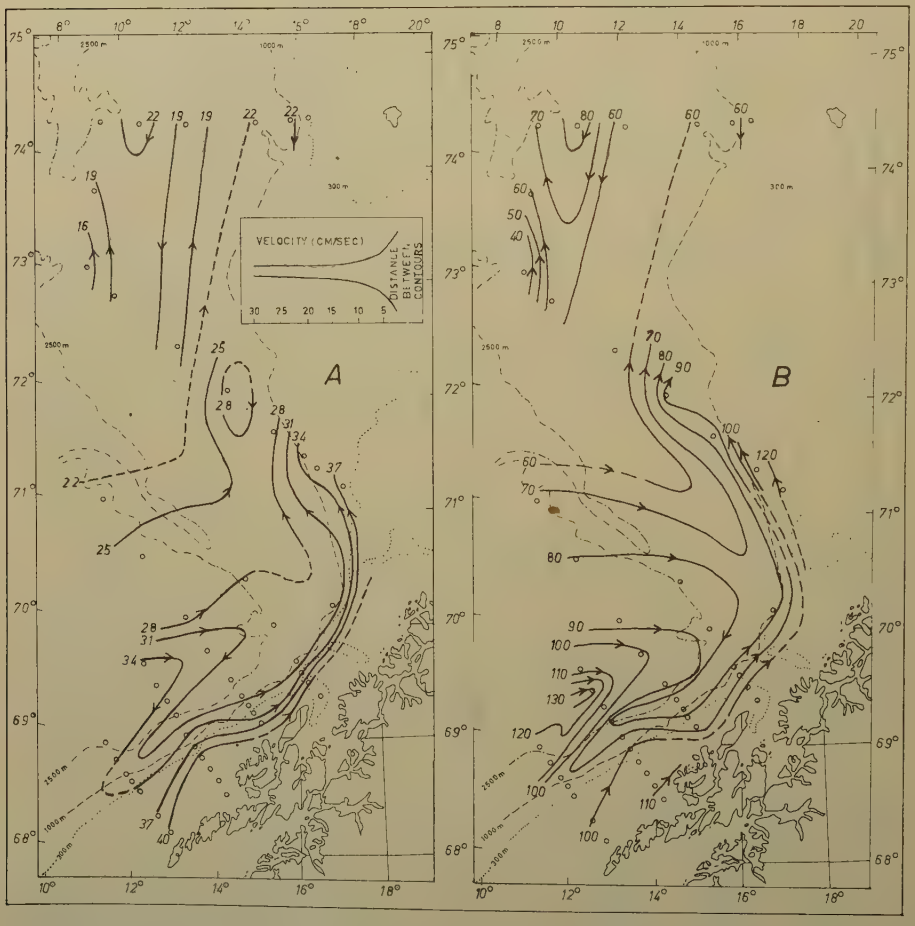

Fig. 14. A) Anomaly of dynamic height of sea surface referred to 1000 db. or bottom (10^2 Δ D). Arrows indicate direction of flow. Inset diagram shows the theoretical relation of the distance between contours to the velocity. B) Volume transport between the sea surface and 1000 m, or the bottom of the relative current (10^{-1} Δ Q).

As evident from Table 1 the greater part (above 50 %) of the relative transport included a rather thick layer off Vesterålen.

Between the st.s 572 and 569 the transport was directed towards the north-east, between the st.s 569 and 567 towards the south-west.

Table 1.
Transport above stated depth in percentage of the total transport.

Depth in m	100	200	400	600	1000
Between st.s 572 and 569	29.6	51.1	81.9	95.8	100
Between st.s 569 and 567	14.6	30.0	57.8	84.2	100

These data, together with the conformity between the course of the isolines in the Fig.s 14 A and B indicate that off the edge the current system was very deep, as also appears from the Fig. 13. In its broad features the current conditions at the sea surface are therefore assumed to have been representative of the upper 100 m.

The Barents Sea (Fig.s 15 and 16 A—B)

The 250 db. surface has been used as a reference. The $\Delta\ \alpha$ distribution and current conditions in the North Cape section are shown in Fig. 15.

The east-going component of the current was strongest in a narrow zone close to the coast, carrying coastal and mixed water. The maximum velocity was 31 cm/sec., but the slope of the isosteres at the reference depth indicate a possible component to the east in this layer. The relative velocity along the coast may therefore have been somewhat higher than calculated.

To the north of the station 666 the current was weak, being directed towards the west in some areas north of the North Cape Bank.

Fig. 16 A represents the relative current at the sea surface, Fig. 16 B the relative volume transport between the sea surface and 250 m. The strongest current and greatest transport occurred in coastal and mixed water in a zone of varying with close to the coast.

To the west of the North Cape Bank one branch of the North Cape Current pushed south-east in the deep channel between the bank mentioned and the Tromsøflaket Bank. Another branch followed the Bear Island Channel north of 72°30′ LN. Between these two branches, above the ridge between the North Cape Bank and the Thor Iversen Bank, both current and transport had a cyclonic appearance.

The splitting up of the North Cape Current is in good accordance

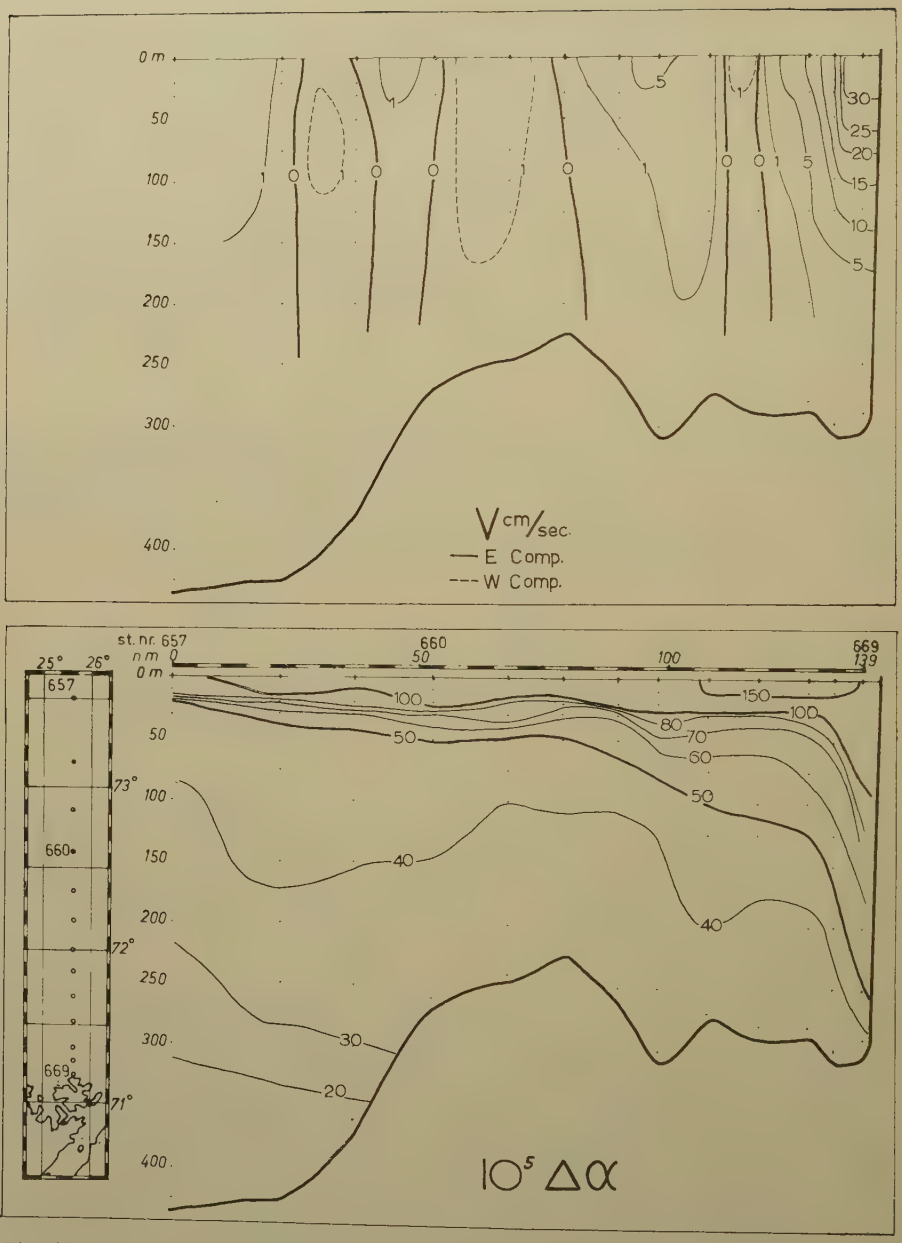

Fig. 15. Specific volume anomaly and current in the section from North Cape to the north.

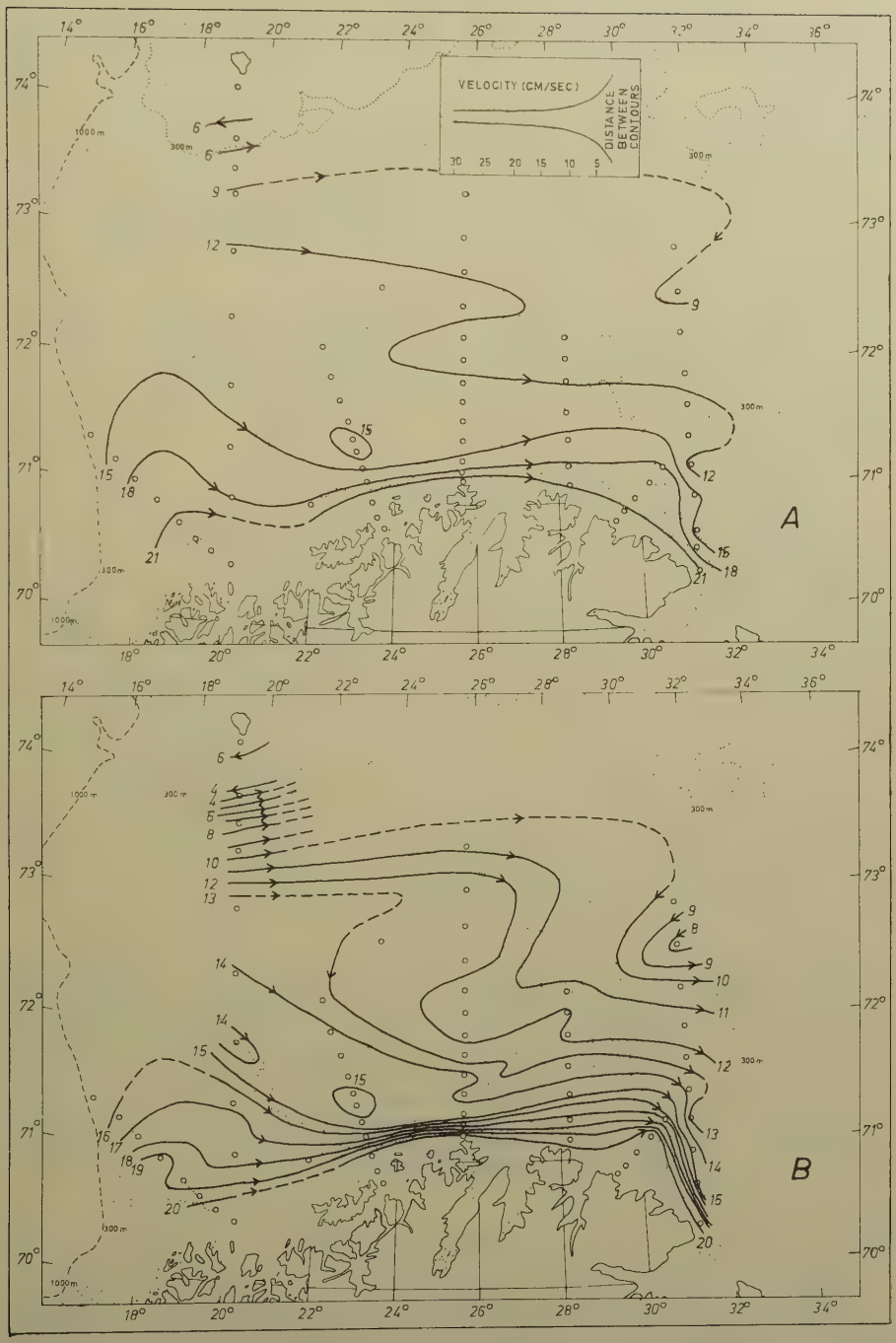

Fig. 16. A) Anomaly of dynamic height of the sea surface referred to 250 db or the bottom (10^2 △ D). Arrows indicate direction of flow. Inset diagram shows the theoretical relation of distance between contours to the velocity. B) Volume transport between the sea surface and 250 db or the bottom of the relative current (10^{-1} △ Q).

with recent information upon the current system of the Barents Sea. (Tantsiura 1959).

On the Tromsøflaket Bank the movement was much more irregular than indicated in the chart. Here an extensive mixing took place between Atlantic and coastal water masses.

By analyzing the conditions in the Barents Sea by methods similar to those used for the deep sea, we may conclude that the current conditions at the sea surface are broadly representative of the upper 50—100 m.

It is of course difficult to ascertain whether the calculated geostrophic currents agree satisfactorily with the movement of the water masses in the region. The absolute geopotential topography of the sea surface depends *i.a.* on the current velocity at the reference depth being zero.

In the deep part of the Sea discussed here, Krauss (1958) suggested the presence of internal tidal waves of great amplitude, represented by a wave-like pattern of isolines in a section outside Andenes, and Zaitsev (1957) suggested that use of hydrographical data observed at different stage of tidal fluctuations may lead to errors distorting the real picture of distribution of dynamic height. Sælen (1959) however, showed that a wave-like appearance of isolines in a section across the Norwegian Atlantic Current must in some cases be interpreted as vortices with vertical axes. The present material does not add anything to this discussion.

A particular difficulty is met with when the bottom depth is less than the reference depth. As previously mentioned, Helland-Hansen's method has been used. Another method, *i.e.* that of Groen (1948), may give a different picture of current conditions, especially in an area where the shallow part of a section is relatively long. Various methods of attacking this problem have been discussed by Sælen, (1959, page 13—15).

In spite of the uncertainties in the dynamic current computed, owing to the reasons mentioned above, there was in many areas a good accordance between the computed and real current conditions. It is well known from experience that outside Vesterålen the current usually has its maximum value above the edge, while off Finnmark the strongest current is in a narrow zone close to the coast.

The Current in Relation to the Distribution of Water Masses (Fig. 17)

As demonstrated in Fig. 17 there was in some areas a reasonable correlation between the currents and the distribution of properties of various water masses. In the north-western part of the investigated area the relatively cold tongue (t below 6°C) of Atlantic water (salinity well

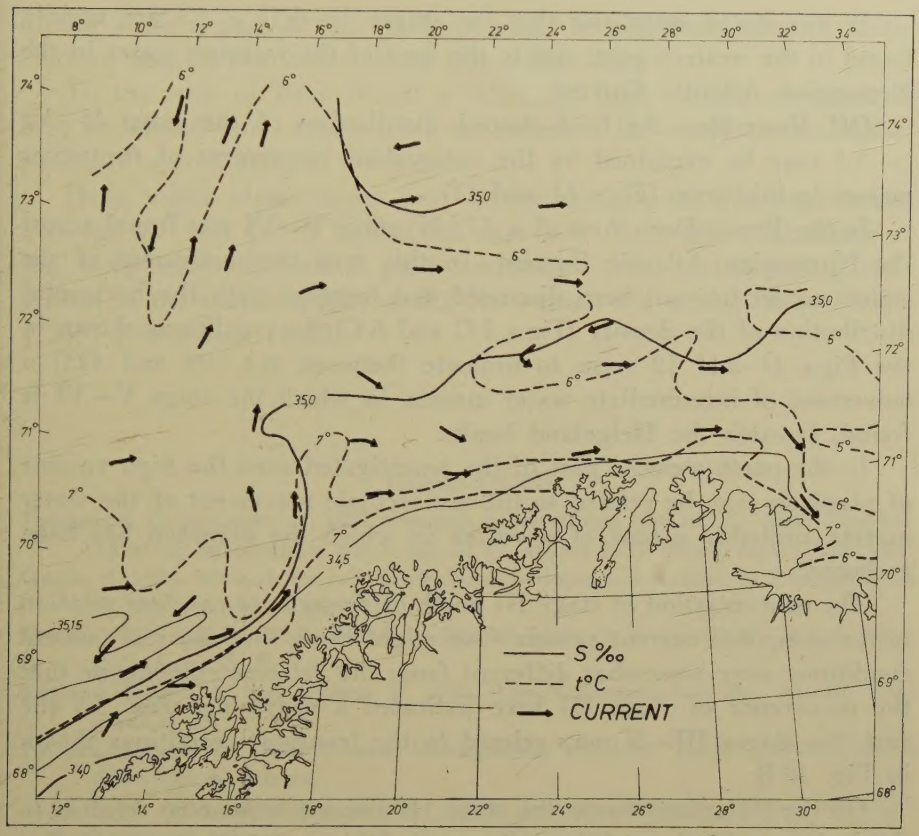

Fig. 17. Distribution of temperature and salinity at 50 m, and the main features of current system at the sea surface.

above 35.0 ‰) may be related to the south-going current branch mentioned before. In the same way the cyclonic movement between the two branches of the North Cape current limited the relatively cold tongue (t below 6°C) of water with salinity around 35.0 ‰.

THE INFLUENCE OF HYDROGRAPHICAL CONDITIONS ON THE DISTRIBUTION OF ZOOPLANKTON

As pointed out by Wiborg (1960) the distribution of the various developmental stages of *Calanus finmarchicus* was related to the hydrographical conditions. A close comparison can now be undertaken between the horizontal distribution of the stages mentioned (Wiborg 1960, Fig. 10 p. 10) and the hydrographical conditions described in this paper.

It was stated *inter alia* that the stages V—VI $>$ 5.5 are mainly found in the western part, and to the west of the warmest water in the Norwegian Atlantic Current.

Off Vesterålen the hook-shaped distribution of the stage V—VI $>$ 5.5 may be explained by the anticyclonic movement of the water masses in this area. (Fig.s 14 and 17).

In the Træna Deep Area (Ca. 67° N) stage V—VI was found across the Norwegian Atlantic Current. In this area the movement of the water masses has not been discussed, but together with the horizontal distribution of the density (Fig.s 5 C and 6 C) the conditions shown in the Fig.s 11 and 12 seem to indicate (between st.s 509 and 525) a movement of intermediate water masses, in which the stage V—VI is found, towards the Helgeland banks.

In the north-western part of the investigated area the high volume of plankton may be related to the anticyclonic movement of the water masses, probably a part of a vortex in which the plankton has been gathered.

The concentration of stage III north of Sørøy bore no clear relation to the computed current system. One might think that the real current conditions were somewhat different from the relative current, or that the occurrence of stage III here indicated a spawning area. To the east, the stages III—V may related to the transport conditions shown in Fig. 16 B.

On the Helgeland banks the stage III seemed to bear no relation to the hydrographical conditions discussed. Wiborg (1960) supposed that this stage distribution refers to a summer spawning of *Calanus finmarchicus* in the Møre area.

SUMMARY

The research was intended to discuss the hydrographical conditions of the water masses in which biological investigations were simultanously undertaken. The data were collected during a cruise in July—August 1957.

Some characteristic features of the different water masses have been described. The horizontal and vertical distribution of these water masses hawe been charted by help of the conditions at selected depths and sections. A computation of the relative current has been carried out in the area off Northern Norway.

A good correlation was found between hydrographical conditions and the distribution of the various developmental stages of *Calanus finmarchus. I. a.* the development of the stages was most advanced

in the western part of the warmest water in the Norwegian Atlantic Current and on the west side of this water mass.

To the west of Bear Island a relatively high volume of plankton may be related to an anticyclonic movement of the water masses, which probably was a part of a vortex.

Deep water observations were undertaken in the Norwegian Sea between 68° and 74° N and to the east of 8° E. A short discussion of this deep water showed a good conformity with corresponding conditions in the southern part of the Norwegian Sea described by Mosby (1959) and Sælen (1959).

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